ADAPTIVE MULTIFILAR ANTENNA

This invention relates to adaptive multifilar antennas.

In fields such as mobile telephony and communication, it is being proposed that radio frequency transceivers operating in different frequency bands, and providing different services, should be integrated into single consumer devices.

For example, in order to improve the coverage area in which a mobile telephone can be used, a satellite system transceiver, a terrestrial transceiver and a domestic cordless telephone transceiver might be integrated into one hand-held unit. An alternative example is a dual service telephone operating at 1800MHz in the user's home country but having the capability of operating at 900MHz in other countries under a so-called roaming arrangement.

The electronics needed to achieve this aim are rapidly becoming smaller and lighter. A remaining problem area for multi-frequency, multi-system operation, however, is the antenna.

In order to operate as described above, an antenna should be able to work at different frequencies and with different types of base station. For example, one service may

use terrestrial base stations and another may use orbiting satellites. This means that if the handset antenna is typically used in a vertical position (with the handset held next to the user's head) then for one service the antenna should have a radiation pattern substantially omnidirectional. in azimuth and for the other service it should have an approximately hemispherical radiation pattern.

To cater for the different pattern and frequencies in use, it has been proposed to employ at least two distinct antennas within a common volute.

In a first aspect, the invention provides an adaptive multifilar antenna comprising:

n spaced filaments, where n is an integer greater than 1;

at least one filament group having a predetermined plurality of the filaments coupled together in a fixed phase relationship;

a weighting circuit operable to apply phase adjustments to signals passed to and/or from the n filaments and/or filament group;

detecting means operable to detect at least one electrical property of the multifilar antenna with respect to the frequency, polarisation and/or direction of propagation of

a signal to be received or transmitted by the multifilar antenna and/or impedance matching of the antenna; and

control means, responsive to the detecting means, operable to control the operation of the weighting circuit to adjust the properties of the multifilar antenna to suit better a current signal to be received or transmitted.

In another aspect, this invention also provides an adaptive multifilar antenna comprising:

n spaced antenna filaments, where n is an integer greater than 1;

at least one filament group having a predetermined plurality of the filaments coupled together in a fixed phase relationship;

a matching circuit for matching the characteristic impedance of the antenna to that of a transmitting and/or receiving apparatus;

a phasing circuit for applying respective gain and phase adjustments to signals passed to and/or from the n filaments and/or filament group;

switch means associated with each filament for selectively altering the electrical length and/or interconnections of the filaments;

means for detecting electrical properties of the multifilar antenna with respect to the frequency, polarisation and/or direction of propagation of a signal to be received or transmitted by the multifilar antenna and/or impedance matching of the antenna; and

control means, responsive to the detecting means, for controlling the operation of the matching circuit, the phasing circuit and the switch means to adjust the properties of the multifilar antenna to suit better a current signal to be received or transmitted.

In the invention, the phase and/or gain relationships for signals from individual filaments of a multifilar antenna, and optionally also with the electrical length and/or interconnection pattern of the filaments, can be varied automatically in order to improve (or possibly to optimise, within the resolution of the adjustment system) the properties of the antenna for a particular signal to be received or transmitted. The automatic variation may be applied identically to predetermined groups of individual filaments.

For example, in embodiments of the invention, at least one of the above parameters could be varied to provide the best received signal level, the best signal to noise ratio,

or the best signal to (noise plus interference) ratio and/or the best VSWR.

The adjustments will generally lead to a change in the antenna's frequency response and radiation pattern (shape and polarisation). It may not matter to the adjustment system what that change is quantitatively; the system may simply measure the output and make adjustments so as to improve the handling of the current signal.

The invention will now be described by way of example with reference to the accompanying drawings, throughout which like parts are referred to by like references, and in which:

Figure 1 is a schematic diagram of a quadrifilar helical antenna (QHA);

Figure 2 is a schematic diagram of an antenna interface circuit;

Figure 3 is a more detailed schematic diagram of one possible implementation of the antenna system of Figure 2;

Figure 4 is a more detailed schematic diagram of another possible implementation of the antenna system of Figure 2;

Figure 5 is an enlarged view of an alternative for the portion of Figure 3 enclosed in dotted lines;

Figure 6 is an enlarged view of an alternative for the portion of Figure 4 enclosed in dotted lines; and

Figure 7 is a plot comparing the diversity performance of differently configured QHAs.

With reference to Figure 1, a QHA comprises four helical elements 10..40 and eight radial elements 50..120. (In other embodiments six, for example, angularly spaced helical elements could be used). It will also be noted that not all the radial elements 50..120 will be present in all antenna configurations.

The helical elements are intertwined as shown in Figure 1, and are disposed about a longitudinal axis of the antenna by 90° with respect to one another. Four of the radials 50..80 are disposed on the top and four 90..120 on the bottom of the volute, connecting the helical elements and forming two bifilar loops. The antenna is fed on one set of radials 90,110 with 90° phase difference between the two feeds.

The radials 50..80 at the top end of the antenna with respect to the feeds (which in this

example are at the bottom) may be shorted in pairs or may be open-circuit depending on the resonant length of the helical elements and the required response.

The QHA is described in the following references:

[1] Kilgus C.C., "Multielement, Fractional Turn Helices", IEEE Transactions on Antenna and Propagation, Vol.AP-16, pp.499-500, July 1968

[2] Kilgus C.C., "Resonant Quadrifilar Helix", IEEE Transactions on Antenna and Propagation, Vol.AP-17, pp. 349-351, May 1969

[3] Kilgus C.C., "Resonant Quadrifilar Helix Design", The Microwave Journal, December 1970.

The antenna's radiation pattern mode (hemispherical or other) depends on the phase combination used on the two or four feeds. The exact shape of the antenna's radiation pattern in each mode depends on the pitch and dimensions of the helices. In the axial mode it has a shape varying from hemispherical to cardioid depending on the dimensions of the structure. The polarisation is circular with a very good axial ratio inside the 3dB angle.

In other embodiments, the multifilar antenna arrangement can also be used for diversity purposes. The different filaments can be used to provide space diversity between generally uncorrelated received signals. The effect of weighting the gain and/or phase can affect both the shape and the polarisation of the radiation pattern. This effect can benefit the transceiver in two ways. Firstly, the pattern shape and the polarisation are matching the direction and the polarisation of the incoming signal to try to optimise or improve the criterion ratio (S/N or S/(N+I), and secondly the structure can be used for polarisation diversity using the resulting pattern of different filaments or pairs of filaments.

Figure 1 shows an antenna which has a generally cylindrical volute (i.e. circular in plan). Other volute shapes such as those having elliptical or rectangular plans or a truncated cone shape are also suitable for use in the present invention.

Figure 2 is a schematic diagram of an antenna system comprising an adapted QHA 200 and an antenna interface circuit.

In Figure 2, the four elements of the QHA 200 are connected separately to an adaptive matching circuit 210. (In the configuration shown in Figure 2, the antenna is in a receive mode, but it will be clear that signals could instead be supplied to the antenna, in a transmit mode, by reversing the direction of signal propagation arrows in Figure

2.) The adaptive matching circuit 210 is under the control of a matching controller 220, which in turn is respective to a system controller 230.

Received signals from the adaptive matching circuit are supplied to four respective variable weighting circuits W1..W4. Each of W1..W4 comprises a variable phase delay and optionally, a variable gain stage, all controllable by the system controller 230.

An alternative which is described in more detail below is to combine diametrically opposite pairs of elements (10,30 and 20,40) with fixed 180° weights at RF so that the antenna has only two feeds (each relating to a respective diametric pair) and therefore requires only two weighting circuits W1,W2 and two transceivers 400 and 450.

In the embodiment of Figure 2, the outputs of the four variable weighting elements W1..W4 are combined by an adder/weight combiner 240 to form a composite signal. This composite signal is then stored in a store 250. A sensor 280 examines the signal (e.g. the level of the signal to (noise plus interference) ratio) and passes this information to the controller which in turn adjusts the weighting factors of the weighting elements W1..W4, the matching circuit 210 and the switch elements 290,300 to improve or possibly optimise the parameter sensed by the sensor 280. The optimisation information can be used to optimise or improve the quality of the stored

signal, which is then passed to the demodulator 260. The information is also used to adjust the antenna system to receive the next incoming signal.

In each element of the QHA, there is a switch 290 capable of isolating a portion of the element remote from the feed point. The switch could be, for example, a PIN diode switch. Similarly, a switch 300 is capable of shorting or isolating pairs of the elements at the end remote from the feed point.

The operations performed by the switches 290 and 300, under the control of a switch controller 310, can change the response and radiation pattern of the antenna. In particular, by isolating a section of each element, the electrical length of the elements is made shorter and so the frequency of operation will be higher. Again, these operations are carried out under the control of the system controller to improve or possibly optimise operation with a particular signal frequency, polarisation and direction of propagation.

Alternatively, or additionally, the antenna element may be caused to have several resonant modes by the inclusion of one or more antenna traps. This causes the antenna to be resonant (and therefore have increased gain) at more than one operating frequency.

Figure 3 is a more detailed schematic diagram of one possible implementation of the antenna system of Figure 2, which also shows operation to improve or optimise the VSWR during a transmission operation and S/N+I during a receive mode. (Incidentally, when S/N+I is improved by adapting the antenna matching in a receive mode, this has an indirect side-effect of tending to improve the VSWR. Also, when the pattern mode, polarisation and direction are improved by adjusting for the best or an improved S/N+I, this similarly has a corresponding improving effect in a transmit mode.)

In Figure 3, the operation of the weighting elements W1..W4 is carried out at baseband in a digital domain, as is the operation of the adder/weight combiner 240.

The output of the adaptive matching circuit 210 is supplied to a quadrature downconverter 400 comprising an intermediate stage 410 where a local oscillator signal is mixed with the radio frequency signal, an amplifier 420 and a further stage of mixing with a local oscillator signal with a 0° and 90° phase relationship to generate two demodulated outputs I and Q. These are both converted to digital representations by A/D converters 430 before being stored in a RAM 440. This process is replicated for each of the elements of the QHA. Similarly, for the transmit side, an output from the RAM 440 is passed to a quadrature modulator 450 before being routed via the adaptive matching circuit 210 to the respective antenna elements.

A VSWR detector 460 operates in a transmit and/or receive mode to detect the standing wave ratio of the antennas. The output of this is stored in the RAM 440.

The RAM is connected to a digital signal processing (DSP) unit 470 which combines the digital representations of the signals stored in the RAM 440 in respective proportions and using respective phases (i.e. performs the operation of the weighting blocks W1..W4), detects and optimises the selected parameter such as signal-to-noise ratio, sends control signals to the adaptive matching circuits to change from one frequency band to another or to overcome de-tuning effects, and also controls the switch controller 310 and in turn the switches 290,300 within the helical elements.

One appropriate DSP algorithm is for the transmitter to send packet header, reference or training symbols, which are known to the receiver. Any disturbance to the received signals during the reception of the training symbols is a measure of N+I and can be reduced by trial and error (repeated combining of the digital representations stored in the RAM 440), direct matrix inversion of the associated correlation matrix or by iteration approaches such as so-called LMS or RLS algorithms. However, even if known training symbols are not available, a measure of the disturbance to the signal can be made by error detection algorithms applied to the received symbols.

Figure 4 is a more detailed schematic diagram of an alternative implementation of the

antenna system of Figure 2. This implementation has a quadrature downconverter 400' which operates in the same way as the downconverter 400 of Figure 3. Similarly, it has a quadrature modulator 450' which operates in the same way as the modulator 450 of Figure 3.

The operation at baseband of the implementation shown in Figure 4 is also similar to that of Figure 3 in that the downconverted signals are converted into the digital domain and stored in a RAM 440'. The data in the RAM is processed by a digital signal processing unit 470' and the DSP 470' is operable to cause changes in the adaptive matching circuit 210' and in the antenna switches 290',300' and 310'.

However, the operation of a circuit of Figure 4 differs significantly from that of Figure 3 in that the weighting operation is performed at RF in weighting blocks 500 which are coupled in the signal path from the individual antenna elements to the quadrature downconverter 400'.

In Figure 4, the weighting block 500 is coupled directly between the adaptive matching circuit 210' and a combiner 240' which operates to additively combine the outputs of the respective weighting circuits W1,W2,W3,W4 contained in the weighting block 500.

The output of the combiner 240' is fed into a single quadrature downconverter 400'. Thus, unlike the implementation shown in Figure 3, only one downconverter 400' is required. Similarly, only one quadrature modulator 450' is required.

This alternative implementation has two main advantages. Firstly, since only one downconverter 400' and one modulator 450' is required, there is a resultant cost saving in the manufacture of the transceiver.

Secondly, since most of the noise in the received signal is introduced by the receiver, there is a fourfold decrease in the noise added by the receiver section since the signal passes through only one (instead of four) downconverters 400'. As a further subsidiary advantage, since the signal from all four antenna elements is subjected to the same noise in the single downconverter 400', it is not necessary to apply gain weightings. Thus the weighting circuits W1,W2,W3,W4 may be arranged only to apply phase adjustments to the signals received by the antenna elements. This simplifies their construction and therefore also has cost and reliability advantages.

In order to optimise the weightings, a slightly different approach may be taken to that used with the implementation of Figure 3. It will be noted that in the implementation of Figure 3, the stored data may be iteratively processed with different weighting applied to the data until an optimal or at least improved result is obtained. However,

in the implementation of Figure 4, the data stored in the RAM 440' already has weighting applied to it and in fact the signals from each of the elements of the antenna have already been combined by the combiner 240'. Thus, in order to find the correct weighting, the weighting are adjusted dynamically during reception of a signal (for example a training sequence). By storing data representing the known weighting settings against data representing the quality of the received signal, it is possible to determine which weighting gives the best reception and/or transmission characteristics. Thus the principles are similar but in the first case (Figure 3) the weighting optimisation may occur "off line" whereas in the implementation of Figure 4, the weighting optimisation occurs "on line" during reception of a signal.

As mentioned above, the number of weighting blocks (and in the case of the embodiment shown in Figure 3, of up and down converters) may be reduced by coupling together predetermined antenna elements. This has the advantage of reducing further the complexity of the circuit and therefore its cost.

In the preferred embodiment using a quadrifilar helical antenna as shown in Figure 1, the predetermined groups of antennas are two groups containing the diametrically opposite pairs of elements 10,30 and 20,40 respectively.

The Table below shows the diversity correlation coefficient matrix for each of the

elements. The figures have been derived from complex coefficients produced empirically. It will be noted that in the table below, the diametrically opposite pairs of elements have correlation coefficients in excess of 0.7.

Table 1 : Diversity parameters for four elements of the QHA

Correlation coefficient matrix	Element 10	Element 20	Element 30	Element 40
Element 10	1.00	0.13	0.75	0.14
Element 20	0.13	1.00	0.17	0.76
Element 30	0.75	0.17	1.00	0.20
Element 40	0.14	0.76	0.20	1.00

Thus, although the grouping of elements is described below in connection with two pairs of elements, on a more general level, the predetermined groups of elements may be groups of elements which are each correlated to within 0.6, preferably 0.7 and more preferably 0.8 or better.

For the quadrifilar helical antenna described below, the pairs of elements are coupled in pairs with a 180° phase shift. This may be achieved using fixed combiners or baluns B1, B2 as shown in Figures 5 and 6.

Looking particularly at Figure 5, it will be noted that the components shown in that Figure can be used to replace the components shown within the dotted outline on

Figure 3. This allows the circuit in Figure 3 to only have two up and down converters 400, 450 which reduces cost. Although Figure 5 does not show an adaptive matching circuit 210, this could be included.

Figure 6 shows the equivalent modification for the circuit of Figure 4. Similarly, the adaptation of Figure 6 could include an adaptive matching circuit 210'.

The circuits of Figures 5 and 6 could also include provision for structure switches 290, 300 or 290', 300' respectively.

The grouping of elements in this way may produce a slightly reduced diversity gain compared to the earlier described circuit in which all four elements are independently adjusted.

However, Figure 7 shows a comparison of the performance of a QHA having four independently adjusted elements and a QHA in which the elements are combined into two pairs, against a standard QHA (which has been normalised to the 0dB level). It will be seen that the diversity gain penalty for using the grouped configuration is only about 1dB in areas of deep shadow with high multipath and that there is an advantage in situations where the signal is not significantly decorrelated between elements (for example, in environments where there is a direct line of sight between the base station

transceiver and the antenna).

Thus it will be seen that the optimal solution will usually be separate control of each element 10..40. However, a very satisfactory compromise may be reached between cost and performance by carefully selecting elements (for example according to their diversity correlation coefficient, however measured) and combining these elements with suitable fixed phase shifts to provide a reduced number of antenna feeds.